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Change from low to high divertor load and edge profiles in comparable H-mode discharges in ASDEX Upgrade

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Introduction

ASDEX Upgrade designed as divertor tokamak with carbon first wall was changed during the last decade from a carbon machine to a tokamak experiment with a tungsten first wall. In 2007 all first wall components including the lower and upper divertor were made from tungsten coated fine grain graphite (FGG). ASDEX Upgrade became the first tokamak experiment with a tungsten first wall [1]. The tungsten coated FGG for high heat load components was proven by a special R&D program. In particular the target tiles for the outer divertor should be capable to receive the 'typical' divertor load for high power (P_{in} = 10-15 MW) discharges of 10 MW/m^2. The high heat flux test facility GLADIS [2] was used to qualify selected target tiles with 200 μm W-VPS coating by cyclic loading with 10.5 MW/m^2 for 3.5 s with a cycle number between 10 and 200. Additionally, single pulses with an increased target load of about 23 MW/m^2 for 1 s were performed resulting in about the same temperature increase as for the cyclic tests but with a higher temperature gradient into the bulk. Nevertheless, the tungsten coating is, compared to graphite as target material, less tolerant against overload.

During the scientific program in 2007/2008 about 1300 H-mode discharges with $P_{heat} \geq 5\ MW$ were performed. From these H-mode discharges about 20% were high power discharges with $P_{heat} \geq 10\ MW$. For most of the discharges this caused no problem for the outer divertor, which is the component with the highest power and energy deposition.

A few discharges show a significant change of the divertor conditions for otherwise the same plasma core parameters resulting in a maximum heat load considerably above 10 MW/m^2 for several seconds overlaid by power spikes of several tens of MW/m² due to ELMs. As a consequence, the tungsten coating at the outer strike line module delaminated at 2 out of 128 tiles [3]. This paper presents the global plasma parameters, edge profiles and divertor loads for these discharges. It shows that it is possible to vary the edge and divertor parameters in a wide range without an impact on the good core plasma performance. For machine safety, it can be learned, that the use of global parameters like input power and radiated power to estimate and restrict the divertor load is not sufficient.

Experiments

This paper compares two improved H-mode discharges with I_p = 1 MA, B_t = -2.5 T, q_{95} = 4.7, and a maximum NBI heating power of P_{NBI} = 12.5 MW. One discharge was run with a clean tungsten first wall. The second discharge was the eighth plasma shot after boronization. ECE diagnostics Li-beam and Thomson scattering were applied to measure edge profiles of electron temperature and density. A new Li beam evaluation algorithm enables to measure profiles up to the pedestal region. The discharges were not optimized for the edge diagnostics so that the edge profiles from Thomson scattering and the Langmuir target profiles have a limited spatial resolution. Divertor thermography was operated with 260 µs time resolution. The bolometer signals were deconvoluted to derive the poloidal distribution of the radiation pattern.

Results and discussion

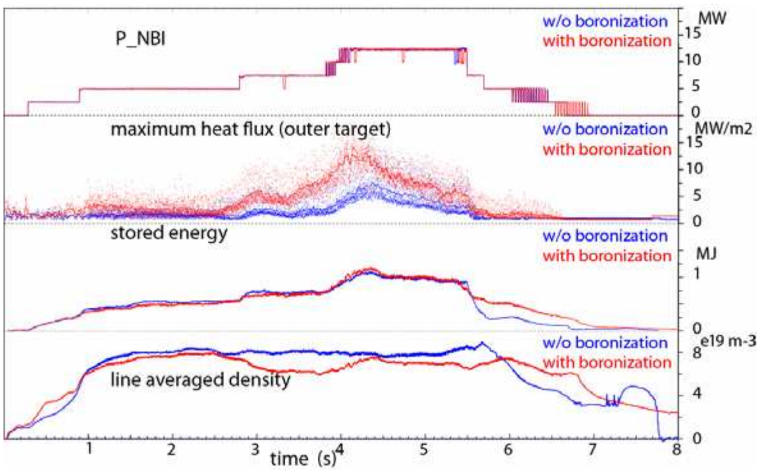

Fig. 1 Time traces for discharges before and after boronization.

Time traces for the NBI heating power, the maximum heat flux to the outer divertor, the plasma stored energy, and the line averaged density, are shown in Fig. 1. The plasma stored energy is the same for both discharges whereas the line averaged density is slightly lower and less stable for the boronized discharge. A significant difference between both discharges is the maximum heat load to the outer target. Whereas the time averaged heat load is in maximum 7 MW/m^2 and therefore below the qualified value for the 'typical' heat load of 10 MW/m^2 for the unboronized discharge, it is with 15 MW/m^2 in the boronized discharge well above this value.

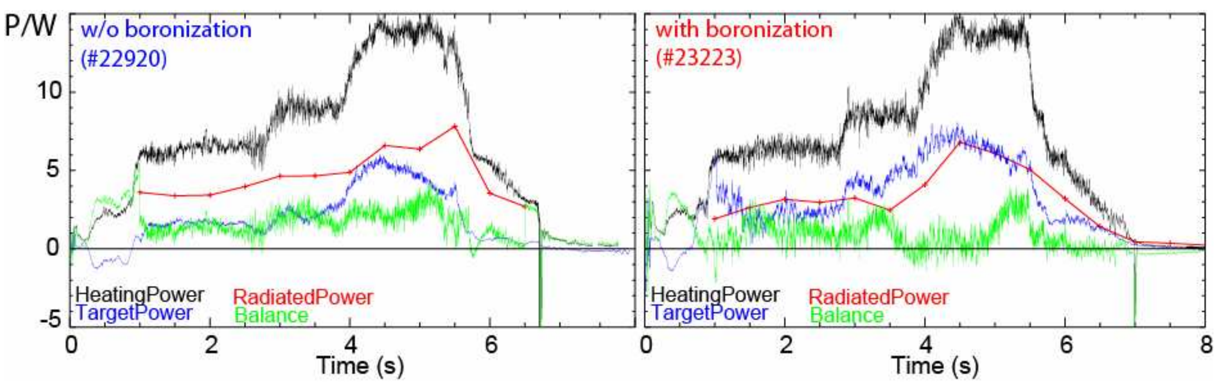

Fig. 2 Power balance for the discharge w/o and with boronization.

The power balance established from the input power, the thermographically measured power to the lower divertor, and the radiated power taken from the deconvoluted bolometer signals are shown in Fig. 2. It is well balanced for the discharge following boronization and is unbalanced by about 15% for the discharge before boronization. From Fig. 2 it is obvious that

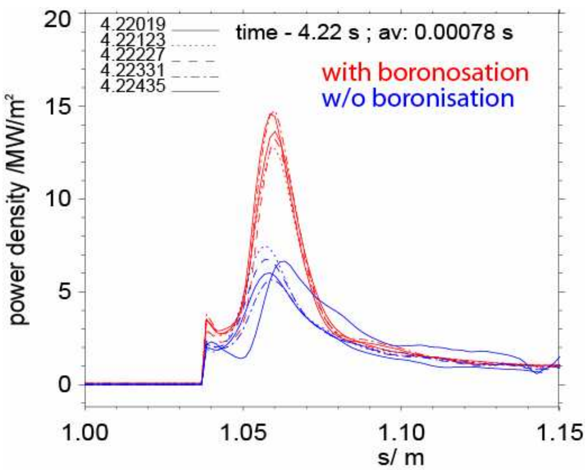

Fig. 3 Heat load in between ELMs to the outer strike line. The profiles are averaged over 4 time slices.

the heat load to the divertor is about a factor of 1.25 higher compared to the unboronized discharge and the divertor load becomes comparable to the radiation losses contrast to the discharge w/o boronization where the dominant loss term is the radiation with about 50 % of the input power. The fraction of power radiated in the divertor is 8% and 9% for the discharge w/o and with boronization, respectively.

The outer divertor target receives about 4 MW or 32% of the input power of 12.5 MW. The reduced radiative loss in the boronized discharge results in an increase of the total power to the outer divertor by 25% to 5 MW. 5 MW deposited power is not a real concern for the outer divertor with an energy receiving capability of 50 MJ. But the higher total load is deposited in a smaller region resulting in an increase of the time averaged maximum heat load by about a factor of two as shown in Fig. 1 and Fig. 4. The e-folding length is reduced from about 15 mm to 8 mm in consistency with an increase of the total power deposited to the outer target by only a factor of 1.25. Results from Langmuir probes in the outer divertor show the same qualitative behaviour as discussed before (see Fig. 3). Electron temperature, density and heat flux are higher with a shorter decay length into the SOL for the discharge with boronization. However, the difference in target heat load calculated from electron temperature and electron density of 35 MW/m^2 and 22 MW/m^2 for the boronized and unboronized discharge, respectively, is less than the factor of two found by thermography. This might be due to the small offset of the separatrix position for the two discharges and the spatial averaging due to poloidal extension of the probe of 5 mm that is in the order of the e-folding length of 8 mm for the boronized case.

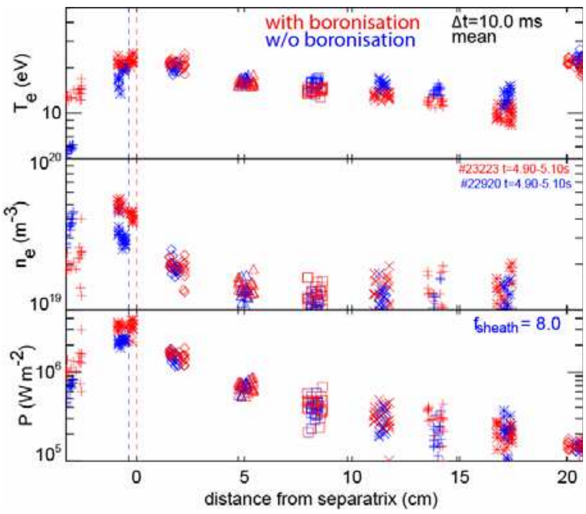

Fig. 4 Outer divertor parameters from Langmuir probes.

Edge profiles of electron temperature and density and the resulting electron pressure as measured by the ECE diagnostics, the Li beam and Thomson scattering in the outer midplane are shown in Fig. 5. The electron temperature is about 20 % higher for the boronized discharge. This is compensated by a slightly lower density so that the electron pressure at

ρ_{pol} = 0.9 is comparable. The e-folding length of electron temperature and pressure is shorter for the boronized discharge. This is consistent with the steeper heat flux profile in the divertor.

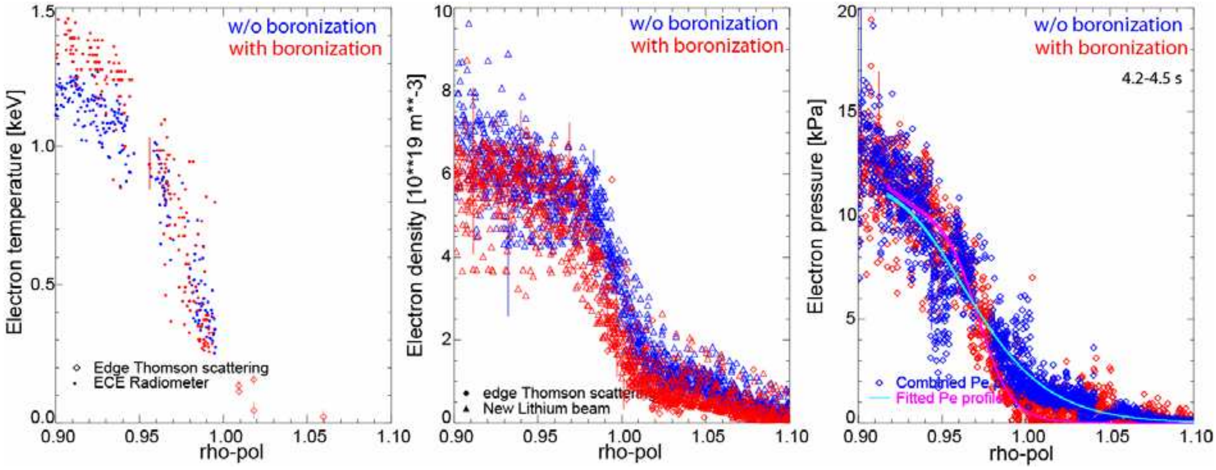

Fig. 5 Edge profiles of Te, ne and the resulting electron pressure.

Summary

ASDEX Upgrade became the first tokamak experiment with a tungsten first wall in 2007. During the experimental campaign experiments with a fresh tungsten wall and with boronization for wall conditioning were performed. Comparable improved H-mode discharges were run with and w/o boronization. Whereas the plasma stored energy and the line averaged density was comparable for the two discharges, the edge behaviour and the power deposition into the divertor show significant differences. The divertor heat load profiles became steeper by a factor of two and the target averaged power was increased by a factor of 1.25 for the boronized discharge. In accordance with this result the edge electron temperature and pressure profile in the midplane separatrix region was found to be steeper too. The electron temperature is about 20% higher and the electron density slightly lower in the pedestal region for the discharge without boronization. The presented experiments show that the heat load into the divertor can be influenced by the wall condition without affecting the performance of the core plasma expressed as plasma stored energy. For machine safety, it can be learned, that the use of global parameters like input power and radiated power to estimate and restrict the divertor load is not sufficient.

References

[1] R. Neu, M. Balden, V. Bobkov, et al., Plasma Phys. Control. Fusion 49 (2007) B59-B70.

[2] H. Greuner, B. Boeswirth, J. Boscary, et al., J. Nucl. Mater. 367 (2007) 1444-1448.

[3] A. Herrmann, H. Greuner, J. C. Fuchs, et al., Physica Scripta (proceedings of the 12th PFMC workshop) to be published (2009).